Brain Mapping of [^{15}O]-H_2O PET Scans Using Statistical Analysis in the Wavelet Domain

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INTRODUCTION

In functional neuroimaging studies, wavelet analysis provides a multiresolution approach to the statistical analysis of brain activation regions. In this work, we present a wavelet-based statistical methodology for detecting activation regions. The method has been compared to the image-domain SPM approach, measuring sensitivity and specificity in a set of simulated [^{15}O]-H_2O PET studies.

METHODS

Simulated [^{15}O]-H_2O PET phantoms

Baseline [^{15}O]-H_2O PET scans were simulated (Fig.1): First, an MR image of a healthy subject was segmented into grey matter, white matter, and cerebral spinal fluid using a validated automatic method. Relative tracer concentrations were respectively set as 100:25:2. The PSF of the PET camera was simulated using a Gaussian filter (FWHM=8x8x6mm). This image was projected at 128 angles, 2:1 decimated, and its global count level set to $5x10^6$. Finally, Poisson noise was added before applying the inverse Radon transform.
Activated scans were similarly generated from the MR image by manually segmenting the thalamus and increasing its original intensity with factors of 2%, 5%, 10%, 15%, and 20% (Fig.1). For each activation factor, 3 baseline and 3 activation scans were obtained.

Wavelet-based statistical analysis

Figure 2 shows a flow-chart of the statistical wavelet-based analysis. For every simulated PET study, a 3D Discrete Wavelet Transform was applied to all scans (Symlets-4; fourth decomposition level). In the wavelet domain, mean images for each condition were subtracted to obtain a between-condition difference image. Student´s t-test was performed to detect wavelet coefficients showing significant between-conditions differences. An activation image in the spatial domain was reconstructed by applying the 3D Inverse DWT to the between-condition difference image with the statistically non-significant coefficients set to zero.
The activation image was thresholded to reduce the noise associated to the ringing artifacts produced by the reconstruction wavelet process. The threshold value chosen was the maximum difference that a Student´s t-test in the spatial domain would consider as non-activated with a statistical power of 80% (α= 0.01).

Evaluation

Evaluation of the wavelet approach was carried out comparing sensitivity at 99% and 95% of specificity for each PET study to that provided by image-domain SPM. The evaluation was also performed using pre-smoothed simulated scans (FWHM=5x5x5mm). Five experimental replications of the study were analyzed.

RESULTS

Sensitivity rates at 95% and 99% of specificity are shown in Figure 3. Figure 4 shows hyperactivity regions detected with the wavelet-based and SPM methods.

DISCUSSION

In PET studies, the wavelet transform allows performing the statistical analysis of activation differences between brain regions in a multiresolution scenario, compacting the relevant information associated to activated areas into a few coefficients. These features seem to yield higher statistical power than image-domain SPM, particularly in low activation and high noise situations. Previous studies presenting similar wavelet-based approaches claimed better results on the sole basis of an increment in sensitivity. Our assessment of the procedure, however, is based on sensitivity and specificity pairs.

CONCLUSIONS

Our statistical wavelet-based method outperform image-domain SPM in the detection of brain activity in simulated [^{15}O]-H_2O PET studies.

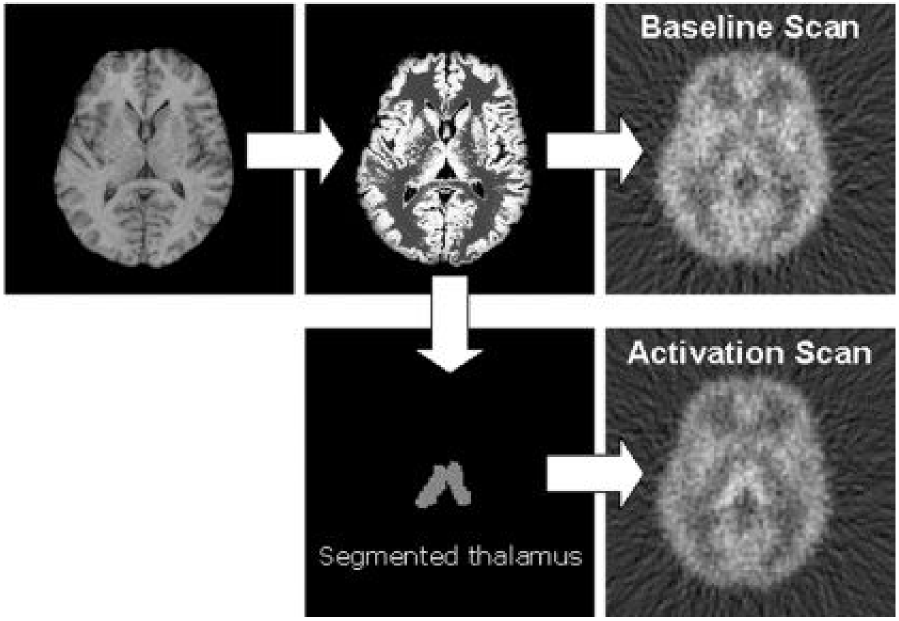

Figure 1. Simulation procedure of [^{15}O]-H_2O PET scans.

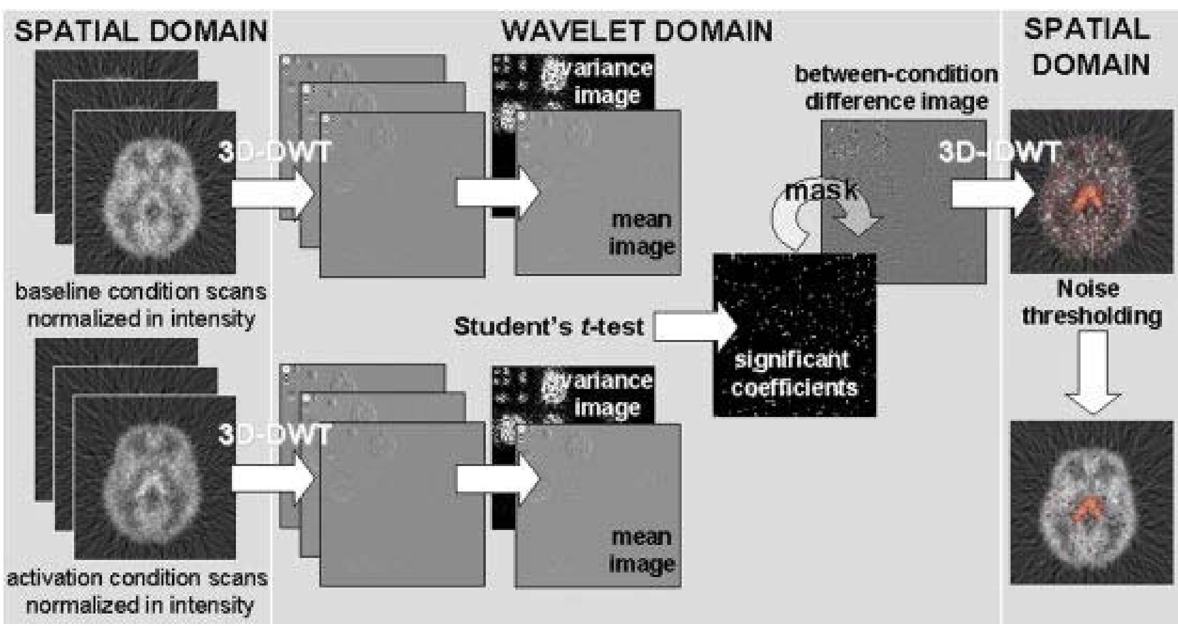

Figure 2. Statistical wavelet-based analysis for detecting brain activation regions.

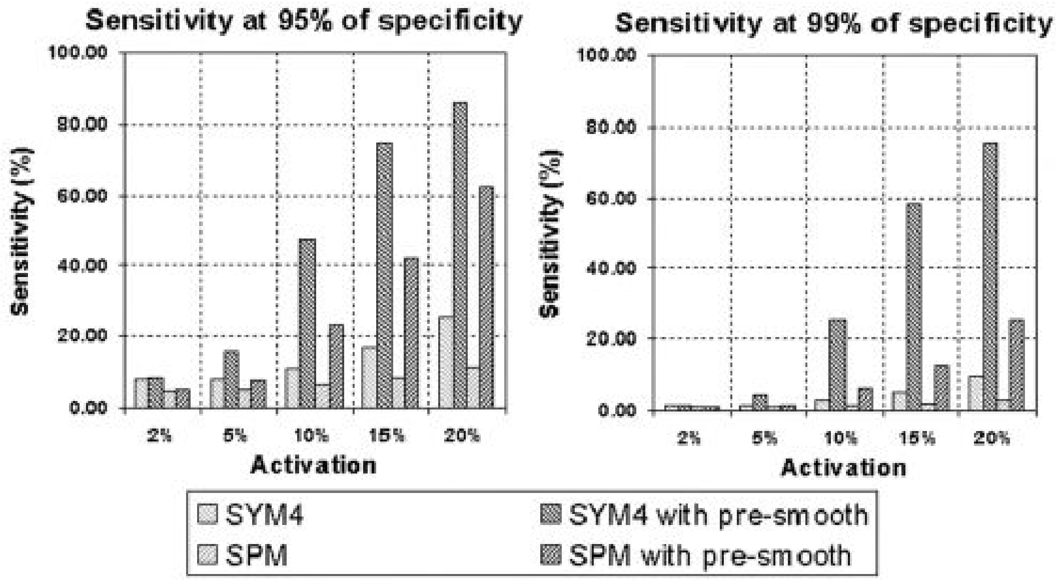

Figure 3. The statistical wavelet-based method substantially outperformed conventional image-domain SPM. When operating on smoothed images, a noticeable increase in performance was observed for both approaches, although the wavelet method still yielded better results.

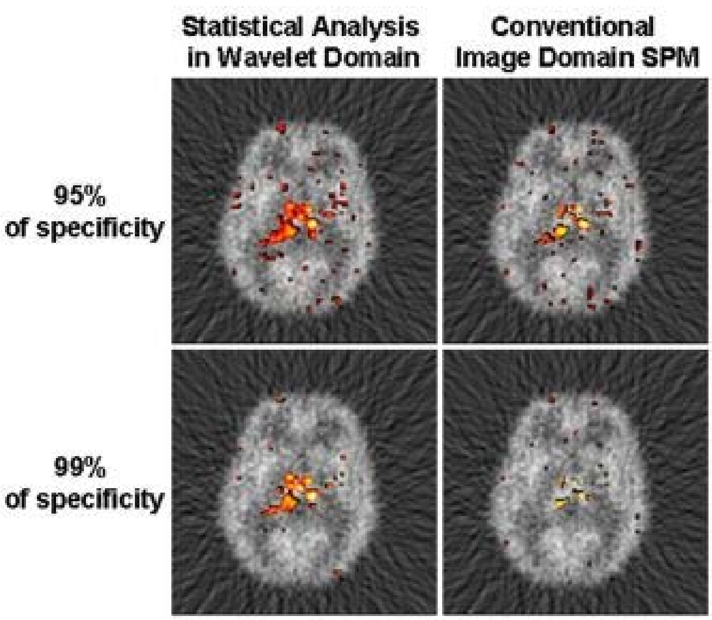

Figure 4. Pre-smoothed study with a 10% of thalamus activation level: at a fixed specificity rate, activation areas are closer in size and shape to real activations with the wavelet method than with SPM.